ling, and no part of the inſide ſuffered in the leaſt, notwithſtanding that the ſtroke, by the prodigious noiſe which accompanied it, ſeemed to be very powerful.

It is remarkable that a perſon was ſitting at the time in a door on the ground floor, not more than 4 feet from the lower end of the copper ſpout, who received no injury, though he very ſenſibly felt the ſhock.

From our obſervations on the above caſe, as well as ſome others that have occurred, we would ſtrongly recommend to thoſe who put up pointed rods, that the lower end be ſunk ſufficiently deep to reach moiſt earth in the dryeſt ſeaſons. And we ſubmit it to thoſe converſant with electrical philoſophy, whether, when there are more rods than one to a building, it might not conduce much to its ſafety to form a good communication between the rods, and likewiſe between them and a copper water ſpout; carrying an iron or copper rod from the lower end of the ſpout a ſufficient depth into the ground.

Thinking it poſſible that the above may afford ſome hints for improving the means, now pretty generally in uſe, for guarding againſt the fatal effects of thunder ſtorms, we have thought proper to lay it before the Society, and ſhall be happy if it receives their approbation.

N°. XVI.

Experiments and Obſervations on Evaporation in cold Air, by C. Wistar, M. D.

Read Sept. 21 1787.

DURING an experiment with a frigorific mixture, I frequently had occaſion to introduce my hand when it was wet, into a cold veſſel, and obſerved that while it was in this ſituation, a ſmoke or viſible vapour aroſe from the moiſture on it, which ceaſed when it was withdrawn into warmer air, and returned upon my replacing it in the veſſel. In

In order to obſerve this proceſs with more accuracy, I fixed an empty tin jar in a tub, and filled the tub with a mixture of ſalt and ſnow, ſo that the veſſel was completely ſurrounded with the mixture, and the air in it was ſoon reduced to the temperature of ſalt and ſnow, or to 0° of Fahrenheit's ſcale.

In this ſituation, I ſuſpended in it, a rag which had been dipped in water of the temperature of 40°—as ſoon as it deſcended within the veſſel, it began to emit ſmoke or ſenſible vapour, and continued doing ſo, a conſiderable time.—While ſmoking it was drawn out, and the ſmoke ceaſed.—After this, it was replaced in the veſſel, and again began to ſmoke.

This was repeated frequently, and always with a ſimilar reſult, ſo that I had no doubt of the fact.—In the firſt caſe in which I obſerved this ſmoke to ariſe, the moiſt body muſt have enjoyed a heat of 98° or near it, as it was my hand; by this experiment it appeared that a moiſt body of 40° would ſmoke alſo in the ſame circumſtances, and I now wiſhed to know whether this would be the caſe with a body ſtill colder.—For this purpoſe a ſmall piece of Ice was ſuſpended in the veſſel, as the rag had been before—it ſmoked when firſt ſuſpended there, this ſmoking ceaſed when it was drawn out, and returned when it was placed in the veſſel again; preciſely as it had happened when the rag was uſed.—Another lump of ice was dropped into the veſſel and allowed to remain there, it ſmoked for twelve or fifteen minutes and then ceaſed.—Snow ſmoked in the ſame manner, but not ſo long.

To be certain that this vapour really aroſe from the ice, a ſmall mirror was ſuſpended horizontally in the cold veſſel—It continued ſo a long time without contracting any moiſture or dullneſs on its ſurface—The ice was then introduced under it, and, although there was a conſiderable diſtance between them, the mirror ſoon became encruſted with

with hoar froſt. To prevent deception, I varied this experiment by placing a tumbler inverted in the cold veſſel—It remained there a long time, and its ſurface, both within, and without, continued free from any moiſture or froſt—I then introduced under it a piece of ice, and in a few minutes, the whole internal ſurface was covered with froſt.

This proved clearly that the vapour aroſe from the ice alone; and during this experiment, another fact of the ſame nature occurred.—When the mirrors or tumblers were removed from the cold veſſel into the air of the room, which was 34°, they ſoon attracted moiſture from it, which appeared on their ſurfaces in the form of ice or froſt; they were replaced in the veſſel when thus encruſted, and the ice ſoon diſappeared, their ſurfaces becoming as bright as before.

The whole of this proceſs was pleaſing,—while the mirror remained in the cold veſſel, its ſurface continued bright, very ſoon after it was placed in the air of the room, it became dull, as if breathed upon, this dullneſs increaſed to an evident moiſture conſiſting of ſmall drops of water, a fibre of ice then formed ſuddenly in the moiſture, a ſecond appeared to ſhoot from this, a third from the ſecond, and ſo on, until the whole was congealed. When this congelation was completed, the mirror was returned to the cold veſſel, and the ice diſappeared in about the ſame ſpace of time in which it had formed.

This collection of moiſture on the ſurfaces of bodies cooled to 0°, and then expoſed to air of 34°, is analogous to the formation of drops of water on the ſurfaces of cool bodies expoſed to the warm air of ſummer, it proves, that even in cold weather, a large quantity of moiſture exiſts in our atmoſphere.

When the ice was in the cold veſſel, I obſerved that it ſmoked but about twelve or fifteen minutes, and ſuſpected that

that perhaps the evaporation continued no longer, to determine this point, I placed two tumblers in the cold veſſel, and when they were cooled, placed a lump of ice in the ſame ſituation and inverted one of them over it—this tumbler became encruſted with froſt as before; it remained twenty minutes and then being removed, the other was inverted over the ice in its place, but although the ſecond tumbler remained a long time in this ſituation, its ſurface continued perfectly free from any moiſture or ice whatever. This reſult appeared to me a full proof that the actual, as well as the apparent evaporation, ceaſed in a few minutes after its commencement; but from the whole of the experiments I was induced to believe that, while the evaporation went on, it was much more rapid in the cold veſſel, than in the open air which was ſo much warmer —to determine this accurately, two lumps of ice of the ſame weight and form, ſhould have been expoſed a given time, one to the air of the veſſel, and the other to the air of the room, and then weighed accurately; but having no nice ſcales, I was reduced to another expedient much leſs exact.—As moiſture is very conſpicuous on mirrors or poliſhed ſurfaces, I thought of comparing one of them which had been moiſtened and placed in the cold veſſel, with another which had been equally moiſtened, but placed in warmer air,—for this purpoſe I took two razors highly poliſhed, and, after expoſing them to my breath ſo that each was equally dull, I placed one of them in the cold veſſel, and at the ſame time, held the other in air of 34°—in ſeveral inſtances the razor in the cold air loſt its moiſture ſooneſt, and in ſome other inſtances, both of them loſt their moiſture ſo quickly, that it was difficult to compare them.

I refrain however from drawing a concluſion from theſe reſults, becauſe when the ſame razors were expoſed to my breath, and then placed, both of them in air of 34°, one loſt its moiſture in leſs time than the other—although this circumſtance

circumſtance leſſened my confidence in the reſult of the laſt experiments, it may be explained upon the ſame principles which explain the others: in the mean time it is certain, that when both, razors after being cooled to 0°, were moiſtened with my breath, and in that ſituation expoſed, one to the open air of 34°, and the other to the air of the cold veſſel, that which was in the veſſel loſt its moiſture, while that in the open room appeared to receive additional moiſture from the air around it.

It has long been known that evaporation continues when the air is below 32°; beſides the familiar fact of drying linen in freezing weather, Mr. Boyle found that the weight of a piece of ice was diminiſhed, by expoſing it to the open air during a cold night—Captain James who wintered at Charlton Iſland in Hudſon's Bay, has related that the ſnow, in that *bitter* cold country, often diſappears without melting. Mr. Wilſon, profeſſor of aſtronomy at Glaſgow, obſerved that a thin cruſt of ice on the caſe of his teleſcope diſappeared while he was making an obſervation, during an intenſely cold morning: he has related this fact in the Philoſophical Tranſactions, and infers from it that evaporation continues in very cold weather.

It therefore is not ſurprizing that evaporation ſhould go on in the cold veſſel, but from all the circumſtances, and eſpecially from that laſt related, reſpecting the razors, I cannot refrain from inferring, that there was more evaporation in the cold veſſel, than in the air of the room, and believe that this fact may be explained without deviating from the true principles of evaporation.

Water unites with the atmonſphere, or evaporates by three proceſſes, which are (to appearance at leaſt,) different from each other.

1. If it be expoſed to air of its own temperature, or warmer than itſelf, it diminiſhes inſenſibly.

2. If its heat be increaſed a certain degree above that of the air to which it is expoſed, a viſible vapour or ſmoke will ariſe from it, which will appear more or leſs in quantity in proportion to the heat.

3. If it be heated to 212°, while expoſed to the preſſure of the Atmoſphere, or to 98° in vacuo, ſmall tranſparent globules are formed ſuddenly, and with a crackling noiſe, in that part of it which firſt receives the heat; theſe globules, which are compoſed of elaſtic vapour, aſcend through the water as quickly as air would do, if in the ſame circumſtances: as ſoon as they eſcape from water into air, which is colder, they are converted from tranſparent elaſtic vapour, into viſible inelaſtic vapour or ſmoke, which paſſes through the air as other viſible vapour does: the formation and paſſage of theſe bubbles through the water, produces that motion in it which we call boiling. * Any perſon may be convinced of this, by applying a candle to the bottom of a flaſk or thin glaſs veſſel which has a ſmall quantity of water in it.

The evaporation produced by immerſing moiſt bodies or ice, in cold air, reſembles the ſecond kind which I have deſcribed (or that which produces ſmoke,) in ſeveral reſpects. In order to make water ſmoke, you need only render it warmer than the air to which it is expoſed; thus, to give a very familiar example, a diſh of tea, when firſt poured out, ſmokes at the fire ſide, when it has loſt ſome of

* I have ſtated that water will boil in vacuo, with a heat of 98° upon the authority of Mr. Watt; but an elaſtic vapour will ariſe from water in vacuo when the heat is much lower.— Some Gentlemen have related in the Philoſophical Tranſactions, that when they were making experiments with the Barometer in an exhauſted receiver, an elaſtic vapour aroſe from the moiſt leathers, and compreſſed the mercury in the Barometer. They alſo refer to the experiments of Lord Cavendiſh, and from theſe they ſay it appears, that water of 72° yielded an elaſtic vapour when the receiver was ſo much exhauſted, that the Barometer ſunk to ¾ of an inch, or when 1-40 of the common preſſure of the Atmoſphere remained; and that when the Barometer ſunk to ¼ of an inch, or that 120 only of the common preſſure remained, the ſame kind of vapour aroſe from water of the temperature of 41°. This fluid therefore when its temperature is 41°. or upwards may be conſidered as in a conſtant niſus to aſſume the form of elaſtic vapour, which niſus is counteracted by the weight of the atmoſphere. See Nairn's accounts of experiments with the air pump, in Phil. Tranſactions, part 2d, 1777.

of its heat this ſmoking ceaſes, but if removed to a colder place, (as the outſide of the window on a froſty day,) it will ſmoke again. Many other familiar facts tend to ſhow, that viſible evaporation or ſmoking, does not depend upon any poſitive degree of heat, but merely upon an exceſs of it in the moiſt body, when compared with the air to which it is expoſed.

The ſmoking of water has been aſcribed by Mr. de Luc, to the paſſage of heat or fire, from the moiſt body into the air around it: he ſuppoſes this fire to carry ſome water diſſolved in it into the air, thus forming ſmoke.

Without entering into the circumſtances of this union of water and heat, I think it may be aſſumed as a general fact, that whenever water and air are in contact, and the heat of the water exceeds that of the air in any conſiderable degree, the paſſage of heat from the water to the air is attended with ſmoking, or the aſcent of inelaſtic viſible vapour.

If this motion of heat and ſmoking are inſeperably connected, the reaſon why ice ſmoked when firſt introduced into the cold veſſel, is very clear, as its temperature was 32° above that of the air in the veſſel.

I do not pretend that this paſſage of heat from moiſt ſubſtances into air is the only cauſe of evaporation, we have already obſerved that water will evaporate into air which is warmer than itſelf as in the ſpecies of evaporation firſt deſcribed, and in the third ſpecies, the elaſtic vapour forms at the bottom of boiling water without any contact with air. But the viſible ſpontaneous evaporation appears different from theſe, and I think that the hypotheſis which ſuppoſes it to depend upon the paſſage of heat, is rendered probable by the following facts which occurred during the above experiments.

1. The ice ſmoked for a few minutes only after it was dropped into the cold air.

2. The ſecond tumbler which was inverted over the ice continued perfectly free from any moiſture or froſt, although the firſt was lined with it.

3. If one of the razors when placed in the cold veſſel, was encruſted with a ſmall quantity of ice or moiſture, this moiſture would ſoon diſappear, but if it was in large quantity, a part only would diſappear, and the remainder continue unchanged, although the razor was kept a long time in the cold veſſel.

Now it is probable that in the firſt and ſecond of theſe inſtances, the evaporation commenced as ſoon as the heat began to flow from the ice to the air, and ceaſed as ſoon as the ice was reduced to the temperature of the air, or as ſoon as the motion of the heat ceaſed.

The ſame I believe happened to the ice on the razor, but the razor being a ſmall body could have contained but little heat, of courſe therefore the evaporation from it muſt have ceaſed before much ice could have been removed.

I cannot think of any principle upon which we can account for the evaporation going on rapidly at one time, and ceaſing at another, except this motion of heat, and there are ſome other facts of conſiderable importance which may be explained by it equally well. Within the Polar regions, when the cold is very intenſe, a ſmoke ariſes from the ſea which is warmer than the air of the land; Crantz the Moravian miſſionary to Greenland, after deſcribing the effects of the violent cold, adds, that " at this time the ſea reeks like an oven," and that this ſmoke is diſtinguiſhed by the inhabitants by the name of *froſt ſmoke*. As the circumſtances attending this ſmoking are ſo ſimiliar to thoſe which attend the ſmoking ice, in the veſſel, there is reaſon to believe that they depend upon the ſame cauſe.

This explanation may alſo be rendered more probable, if it can be made to appear that a proceſs the reverſe of evaporation depends upon a principle the reverſe of that

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we have mentioned as one of the caufes of evaporation. The procefs alluded to is that by which moifture is collected on the furfaces of cold bodies expofed to warm air—Dr. Franklin has explained this upon the principle that the water in the atmofphere is combined with heat, and that it is collected on the cold furface in confequence of the paffage of this heat into the cold body. This explanation is the reverfe of that which I have adopted, and as it explains to the fatisfaction of every one, a procefs the reverfe of evaporation, it ftrengthens that explanation.

When confidering this theory of our great philofopher, and the pleafing application of it to many important proceffes of nature, it occurred to me to try the converfe of the propofition; for if the collection of moifture on the furface of a body depends upon the abftraction of heat from the air by it, it follows, that when a body is not in a condition to receive heat from the atmofphere, no moifture can collect upon it.

As mirrors fhow the prefence of moifture with fo much accuracy I heated one of them, and found that although, when below 98°, they are covered with mift, if expofed but a moment to the breath, yet when heated but little above 98°, I could not imprefs any moifture upon it, although it was applied clofe to my mouth and breathed upon very frequently. Dr. Franklin's propofition requires nothing to confirm it, but if it were doubtful, this laft experiment would furnifh a ftrong argument in its favour.